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IS 13946-1 (1994): Determination of rock stress- Code of practice, Part 1: Using hydraulic fracturing technique [CED 48: Rock Mechanics]



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“Knowledge is such a treasure which cannot be stolen”

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शैल प्रतिबल ज्ञात करना — रीति संहिता

भाग 1 द्रवचालित विभंजन तकनीक का उपयोग करते हुए

Indian Standard

**DETERMINATION OF ROCK STRESS —
CODE OF PRACTICE**

PART 1 USING THE HYDRAULIC FRACTURING TECHNIQUE

UDC 624.121.5

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

FOREWORD

This Indian Standard (Part 1) was adopted by the Bureau of Indian Standards, after the draft finalized by the Rock Mechanics Sectional Committee had been approved by the Civil Engineering Division Council.

Vertical stress on a rock mass varies in a more predictable fashion than horizontal stress because the former is primarily affected by the weight of overburden.

When an opening is introduced in the rockmass, the natural state of stress is disturbed locally as the rock mass attains a new state of equilibrium. The stress around an opening resulting from various man-made activities is termed 'induced stress' as opposed to virgin stress or absolute stress which describes the original, undisturbed state of stress. The natural state of stress is often termed as *in-situ* stress.

Underground *in-situ* stress is sometimes sufficiently high (relative to the rock mass strength) to cause rock bursting spalling, buckling, heaving, or other ground control problems. In such cases, knowledge of the state of *in-situ* stress is of critical importance to the design and construction of engineering structures in a rock mass. Even in cases where the effects of stress are less dramatic, the optimum shape, orientation and layout of underground structures, as well as the effectiveness and ultimate cost of rock support systems, can be significantly influenced by the *in-situ* stress.

Factors affecting the magnitudes and orientation of *in-situ* stress include the weight of overlying and materials, geologic structures (on local and regional scales), tectonic forces within the earth's crust, residual stress and the thermal stress. The complexity of the relations between these factors and the *in-situ* stress usually prohibits reliable estimation of rock stress. In addition, stress cannot be measured directly, and therefore, rock stress determination techniques rely on the measurement of some response (e.g. displacement, strain, deformation) that is induced by a disturbance of the rock mass. This measured response of rock in a stress-disturbed zone (e.g. the wall of a tunnel) is extrapolated, from the opening outwards, through a numerical model or analytical techniques; or measurements must be made via a drillhole that extends into an undisturbed region of the rock mass.

Several methods have been tried to arrive at a reliable means of measuring *in-situ* stress. Each offers different advantages and disadvantages with respect to a particular application.

Different methods for measurement of rock stress have been covered in following four parts which have got wide acceptance:

- Part 1 Using the hydraulic fracturing technique
- Part 2 Using a USBM type drillhole deformation gauge
- Part 3 Using CSIR- or CSIRO-type cell with 9 or 12 strain gauges
- Part 4 Using flatjack technique

Hydraulic fracturing technique is the only rock stress determination technique that has been successfully applied to deep drillhole. This technique has, therefore, found application in *in-situ* characterization investigations via vertical drillholes from the surface. Hydrofracturing may also be done across pre-existing joint holes in the drillhole and values of *in-situ* stresses to be obtained.

The committee responsible for the formulation of this standard is given at Annex A.

Indian Standard

DETERMINATION OF ROCK STRESS — CODE OF PRACTICE

PART 1 USING THE HYDRAULIC FRACTURING TECHNIQUE

1 SCOPE

1.1 This standard (Part 1) covers the method of determination of the state of *in-situ* stress underground through a drill hole using hydraulic fracturing technique.

The test provides, in general, the magnitudes and direction of the maximum and minimum stresses in the plane perpendicular to the drill hole.

2 REFERENCES

The following Indian Standards are necessary adjuncts to this standard:

IS No.	Title
11315	Method for the quantitative description of discontinuities in rock mass:
(Part 1) : 1987	Orientation
(Part 6) : 1987	Aperture
11358 : 1987	Glossary of terms and symbols applicable to rock mechanics

3 TERMINOLOGY

For the purpose of this standard, the definitions given in IS 11358 : 1987 shall apply, in addition to the following.

3.1 Fracture Initiation Pressure

During pressurization as the pressure is increased both tangential and vertical stresses may become tensile. Fracture will occur if the induced tensile stress reaches the drill hole rupture strength.

The drill hole fluid pressure at the moment of drillhole rupture is termed as fracture initiation pressure or breakdown pressure.

3.2 Shut-in-Pressure

After injecting a sufficient volume to propagate fracture length equal to about three times the drillhole diameter, injection is stopped and hydraulic system is sealed or shut-in yielding the instantaneous shut-in-pressure.

4 SYMBOLS

For the purpose of this standard, the following symbols shall apply:

H	= depth at test zone below ground level;
P_b	= static pressure head of fracture fluid;
ν	= mass density of rock;
P_o	= initial pore water pressure;
P_f	= fracture initiation pressure;
P_p	= pumping pressure;
P_s	= instantaneous shut-in pressure;
P_r	= fracture reopening pressure;
σ_v	= vertical stress;
σ_{min}	= minimum horizontal stress;
σ_{max}	= maximum horizontal stress; and
T	= drillhole rupture strength of the rock.

5 APPARATUS

5.1 Drilling Equipment

5.1.1 Any drilling equipment capable of producing a stable hole to the required test depth may be used. The hole diameter should suit the available packer equipment or *vice versa*.

5.1.2 The drilling equipment should also be capable of obtaining core samples in the vicinity of the test sections in order to evaluate drill-hole rupture strength and to examine discontinuity orientations and characteristics.

5.2 Packer Equipment (see Fig. 1)

Packer equipment shall comprise the following:

- a) A system to isolate a test section of drill-hole. Inflatable packers, through which a water flow pipe runs, shall be used to seal the holes enabling a test section to be pressurized. Double packer system, which isolate a part of the hole, shall generally be used, but a single packer, which isolates the base of a hole, may also be considered. For setting the packers and seal the test interval hydraulic or gas expansion shall be used. The

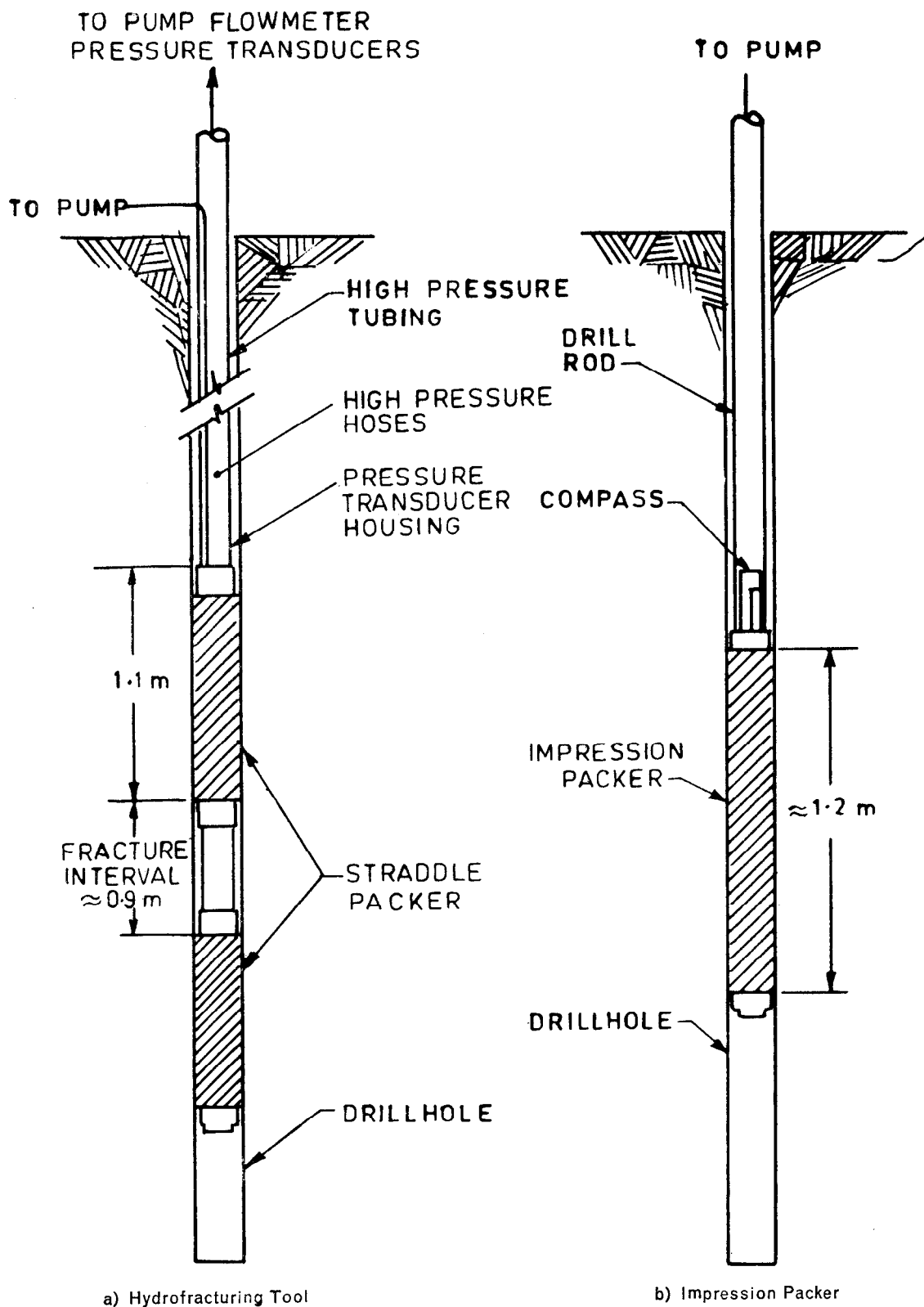


FIG. 1 SCHEMATIC REPRESENTATION

initial packer setting pressure depends on the packer type. If the internal pressure approaches the packer pressure, the packer pressure should be increased to a level sufficient to prevent leakage past the packers.

- b) For separating the packers spacers shall be used. The length of the test section shall be chosen from the observation of core and/or drillhole wall conditions by means of methods described in 5.5. A minimum length of five times the drillhole diameter is commonly recommended. The packers should provide.

5.3 Fluid Injection Equipment

Fluid injection equipment shall comprise the following:

- a) A high pressure pumping system capable of maintaining a constant flow over the range of pressure expected during the test.

The pumping system should have sufficient capacity to overcome the friction-losses in the supply rods and to initiate hydrofractures.

- b) Sufficient supply rods, tubing or hose usually used to lower the packer into the drillhole.

5.4 Inspection Equipment

Any of the following equipments may be used to find the direction of hydrofractures:

- a) Drillhole periscope or television camera for visual inspection. A video recording of a pretesting observation is advantageous for comparison purposes.
- b) Acoustic televiewer.
- c) Drillhole caliper which is helpful to ensure that the designated test section is of suitable diameter for satisfactory seating of packers.
- d) Orientation tool to measure alignment and straightness in case of any indication of excessive deviation.
- e) Magnetic compass used to orient cameras or televiewers for impression packers. Alternate means of orientation shall be used in the mineralogy of the rock which is likely to affect the compass reading. Magnetic rich rock (that is iron formations or basic igneous rocks) may be suspect. Gyroscopic compasses, which maintain the orientation of the inspection device from the hole collar, may be used.

5.5 Measuring Equipments

Following measuring equipments shall be used:

- a) Pressure transducers for measurement of fluid pressure at the surface or immediately above the packer.
- b) A pressure gauge or transducer to measure packer inflation pressure with a compatible level of accuracy to the interval pressure gauge.
- c) Instrument to record fluid flow with time.

6 PROCEDURE

6.1 Drilling and Inspection

6.1.1 Hole diameter and size of downhole hydraulic fracturing equipment shall be selected based on the equipment available. After determination of the test location and depth, a drillhole should be sunk beneath that depth to provide the test intervals. Final choice of the test zone length and depth shall be made based upon the fracture characteristic of recovered cores or on inspection of the drillhole wall by an optical or acoustic logging tool.

6.1.2 Rock cutting and/or cores shall be examined in detail to determine rock characteristics at the test horizons. The choice of packers and inflation pressure may be affected by rock hardness and roughness of the drillhole wall.

6.1.3 To clear the passage for the packer assembly hole may be flushed to remove debris and/or the drill bit may be lowered to the test depth to clear the passage for the packer assembly.

6.1.4 The orientation and apertures of geological discontinuities with the test section shall be estimated and recorded in accordance with IS 11315 (Part 1) : 1987 and IS 11315 (Part 6) : 1987 respectively. This also serves as a pre-test run of the fracture orientation measurement.

6.1.5 A drillhole caliper log in order to avoid placing packers in oversized sections of the hole is recommended.

6.1.6 The packer assembly shall be inserted to the predetermined depth, the depth shall be recorded, and the packers are inflated to a pressure sufficient to seal against the applied fluid pressure.

6.1.7 When filling the injection tubing, care shall be taken to eliminate air from the system. Trapped air greatly increases the compressibility of the system and has an adverse effect on the rate of pressure build-up during test interval pressurization.

7 TESTING

7.1 Pressure shall be monitored either at the ground surface or within the test location. When the pressure is monitored at the ground surface, the pressure in the test interval shall be increased slowly to ensure minimal pressure losses in the tubing. When pressure is monitored within the test section, pressure losses are unimportant. No standard for pressurization rate or flow rate exists; however a common range of pressurization rate of 0.1-2.0 MPa/sec may be followed. The pressurization rate shall be controlled by the constant flow rate selected. The appropriate flow rate to achieve the desired pressurization rate shall vary depending on the overall compressibility of test system, which largely reflects the elasticity of the tubing, the length of the tubing, the compressibility of the fluid and the volume of fluid in the test system. In general, deep tests with large diameter tubing shall require higher flow rates than short-hole tests with smaller diameter tubing.

7.2 The packer pressure should be initially set well below the anticipated breakdown pressure; the packer pressure should be increased at the same rate as the injection pressure. The procedure reduces the possibility of fracture initiation caused by the packer pressure. However, after the rough range of hydrofracturing pressure, at a particular site is known, the subsequent packers can be inflated to the desired/required pressure in single stage. The test interval pressure shall be recorded against time. As pressure increases, both tangential and vertical effective stresses can become tensile. Evidence of failure shall be obtained from pressure time curve and fracture initiation pressure shall be noted.

7.3 After injecting a volume sufficient to propagate a fracture length equal to about three times the drillhole diameter, injection shall be stopped and the hydraulic system shall be sealed or shut in yielding the instantaneous shutting pressure (P_s). Additional pressurization cycles shall be used to determine the fracture reopening pressure (P_r) and additional measurements of the shut-in pressure (P_s).

7.4 Subsequent repressurization cycle should be conducted at similar, constant flow rates, higher or lower flow rate cycles may be added at the discretion of the operator. Use of higher or lower flows rate cycles in the stress calculation should be specified and explained in the report of results.

7.5 After the test is completed, the packers shall be deflated and the equipment shall be recovered from the drillhole. Care should be taken that the packers are fully deflated before attempting to move them.

7.6 The hole inspection shall be carried out to observe and record hydrofracture positions and orientation.

7.7 The drillhole rupture strength of the rock may be estimated from laboratory tests on core samples or may be obtained *in-situ* by comparing the fracture initiation pressure with subsequent reopening pressure.

8 CALCULATIONS

8.1 Where the pumping pressure is measured directly at the test zone, P_t , P_s and P_r may be obtained directly from the time versus pressure plot (see Fig. 2).

Figure 2 presents an idealized hydraulic fracturing pressure record. The general form of the pressure record depends on the relative magnitudes of the principal stresses.

When the plane of hydrofracturing is nearly parallel to the drillhole axis, the following expressions may be used to obtain the principal stresses:

$$\sigma_{\min} = P_s$$

$$\sigma_{\max} = T - 3 P_s - P_t - P_o$$

(for initial pressurization cycle)

$$\sigma_{\max} = 3P_s - P_r - P_o$$

(for subsequent repressurization cycle)

The drillhole rupture strength (T) is determined from laboratory tests, which model the hydraulic fracturing process (preferable) or the tensile strength obtained from direct tension, or Brazilian tests. Appropriate corrections for the effects of sample size and test configuration may need to be made. The vertical stress is usually assumed to be the stress generated by the depth and density of overlying rock. The direction of $\sigma_{\max}$ is in the fracture plane and orthogonal to $\sigma_{\min}$.

9 REPORTING OF RESULTS

9.1 General Information

The report should include the following general information:

- a) A description of the test site location.
- b) A geotechnical log of the test section giving all available information and including the recorded geological discontinuity characteristics and drillhole wall conditions.
- c) A geological description of rock tested, including rock type and availability of core.

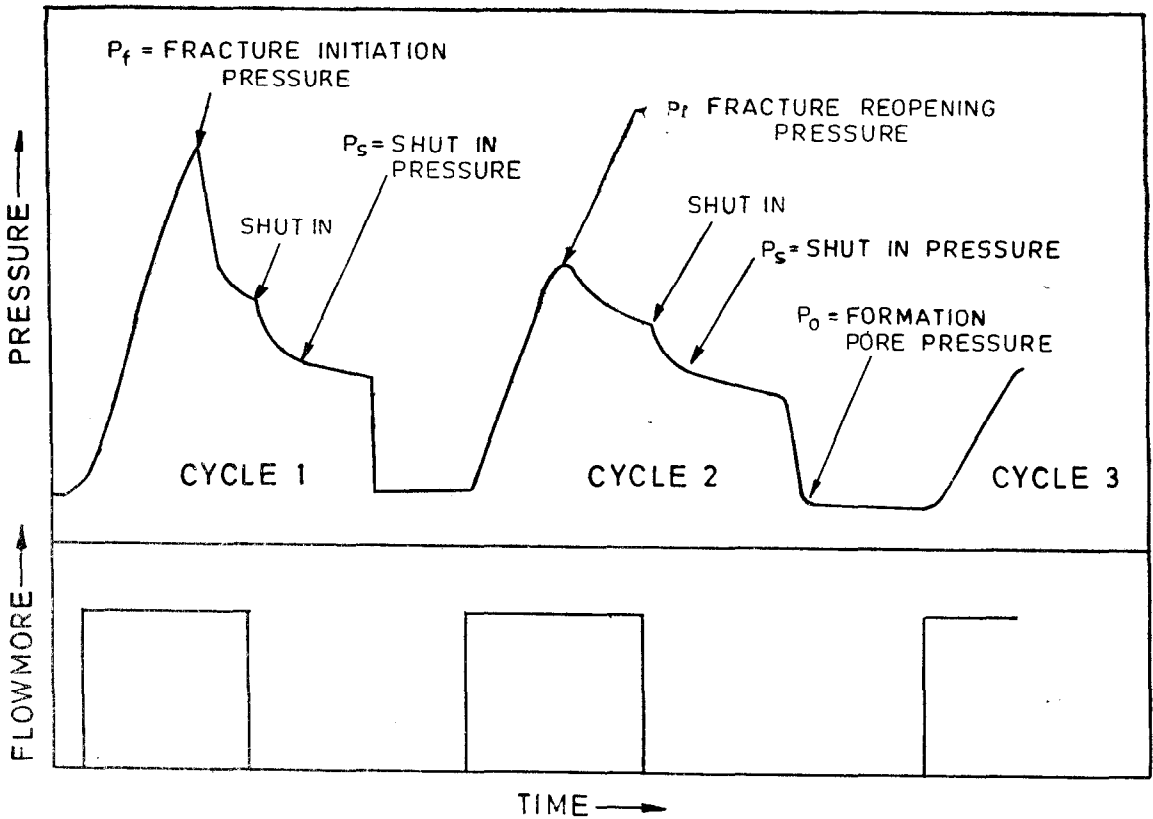


FIG. 2 IDEALIZED HYDRAULIC FRACTURING PRESSURE RECORD

- d) The test depth, length of the test zone and drillhole size.

10 DETAILED INFORMATION

The report should include the following detailed information for each measurement location:

- Graphs showing pumping or flow rate, injection pressure versus time for each test and a description of the method(s) used to selection P_f , P_s and P_r , if distinct pressures are not obvious.
- Tabulated values of H , P_r , P_0 , P_f , P_s , P_r maximum and minimum horizontal stresses and stress directions.

- c) Representations of fracture tracers, constructed from impression packers, on photographs and/or acoustic televiewer logs of test intervals.

- d) A description of the method used for calculating σ_{max} . In case the drillhole rupture strength is determined by laboratory tests, the laboratory test results and the method of data reduction, including equations used, should be reported in sufficient detail.

Test results showing substantial discrepancies with other data and giving possible or probable explanations of the causes.

ANNEX A

(Foreword)

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Rock Mechanics Sectional Committee, CED 48

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Members

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SHRI P. J. RAO (*Alternate*)

SHRI J. VENKATRAMAN,

Director (Civ Engg)

Representing

University of Roorkee, Roorkee

Irrigation Department, Government of Uttar Pradesh
Himachal Pradesh State Electricity Board, Shimla
Irrigation Department, Haryana

Asia Foundations & Constructions Ltd, Bombay

Central Mining Research Station (CSIR), Roorkee

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SMT NEETA SHARMA

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(Continued on page 7)

(Continued from page 6)

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Convener

SHRI U. S. RAJVANSHI

Members

PROF K. B. AGARWAL

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RESEARCH OFFICER (Alternate)

DR A. K. DUBE

PROF A. K. GHOSE

PROF V. D. CHOUBEY (Alternate)

SHRI B. M. RANE GOWDE

SHRI V. K. MEHROTRA

SHRI G. S. MEHROTRA

SHRI U. N. SINHA (Alternate)

SHRI D. M. PANCHOLI

SHRI U. D. DATIR (Alternate)

DR G. V. RAO

DR K. K. GUPTA (Alternate)

RESEARCH OFFICER (SR & P DIVISION)

SHRI B. K. SHARMA

DR V. M. SHARMA

DR R. B. SINGH (Alternate)

SHRI VITTAL RAM

Representing

U. P. Irrigation Research Institute, Roorkee

University of Roorkee, Roorkee

Department of Irrigation and Power, Government of Punjab

Central Mining Research Station (CSIR), Dhanbad

Indian School of Mines, Dhanbad

Central Water and Power Research Station, Pune

U. P. Irrigation Research Institute, Roorkee

Central Building Research Institute (CSIR), Roorkee

Irrigation Department, Central Designs Organization,
Gandhinagar

Indian Institute of Technology

Maharashtra Engineering Research Institute, Nasik

National Hydroelectric Power Corporation Ltd, New Delhi

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Department of Irrigation, Government of Haryana

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BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones : 331 01 31, 331 13 75

Telegrams : Manaksanstha
(Common to all offices)

Regional Offices :

Central : Manak Bhavan, 9 Bahadur Shah Zafar Marg
NEW DELHI 110002

Telephone

{ 331 01 31
{ 331 13 75

Eastern : 1/14 C. I. T. Scheme VII M, V. I. P. Road, Maniktola
CALCUTTA 700054

{ 37 84 99, 37 85 61
{ 37 86 26, 37 86 62

Northern : SCO 445-446, Sector 35-C, CHANDIGARH 160036

{ 53 38 43, 53 16 40
{ 53 23 84

Southern : C. I. T. Campus, IV Cross Road, MADRAS 600113

{ 235 02 16, 235 04 42
{ 235 15 19, 235 23 15

Western : Manakalaya, E9 MIDC, Marol, Andheri (East)
BOMBAY 400093

{ 632 92 95, 632 78 58
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